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Analysis of CREW 3.1 System Center of Mass (COM)

by Michael LaFiandra and Richard Kozycki

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14. ABSTRACT The CREW 3.1 System is an Improvised Explosive Device (IED) jamming device that is worn on the back of a Warfighter. Jack human figure modeling software (Siemens, 2010) was used to help examine the load placement and center of mass (COM) for dismounted Soldiers wearing the CREW 3.1 System and possible implications for metabolic cost. The composite COM of the CREW 3.1 System and the Soldier (including Interceptor Body Armor [IBA], Small Arms Protective Inserts [SAPI], and a full hydration system) was calculated using the methods outlined in Winter (1990) and based on the joint locations of a standing Jack figure. Three digital human models of Soldiers (95th, 50th and 5th percentile male by body weight) wearing IBA with two SAPI plates and a full hydration system were compared to the same three models wearing IBA with two SAPI plates, a full hydration system, and the CREW 3.1 System. In general, the effect of carrying the CREW 3.1 System is to raise the composite COM and to shift it further back from the carrier. Based on the relatively small amount of COM shift that occurs, it is likely that the effect of this shift on metabolic cost is very small.						
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1. Summary

The CREW 3.1 System is an Improvised Explosive Device (IED) jamming device that is worn on the back of a Warfighter, weighs about 20 lbs and has an integrated backpack harness. The location of the center of mass (COM) of a backpack relative to the carrier's COM affects the metabolic cost of walking with the backpack (Obusek et al., 1997), with COM locations that are lower to the ground and further posterior from the carrier resulting in greater metabolic cost compared to a higher, closer to the body COM. The purpose of this evaluation was to determine the effect of the mass and COM of the CREW 3.1 backpack on the composite COM of a Soldier wearing body armor, a hydration system, and the CREW 3.1 backpack.

For this modeling effort, the Jack human figure modeling software (Siemens, 2010) was used to help examine the load placement and COM for a dismounted Soldier wearing the CREW 3.1 System. Three human figure models were used to examine the load carrying effect of the CREW 3.1 System. The stature for each of the corresponding figures were set at 95th, 50th and 5th percentile male values based on the 1988 U.S. Army Anthropometry Survey (ANSUR) (Gordon et al., 1989). Body weights were determined to be 216.21, 171.27, and 135.78 lb. These are the body weights for the 95th, 50th and 5th percentile male Soldier (Gordon et al., 1989).

The composite COM of the CREW 3.1 System and the Soldier (including Interceptor Body Armor [IBA], Small Arms Protective Inserts [SAPI], and a full hydration system) was calculated using the methods outlined in Winter (1990) and based on the joint locations of a standing Jack digital human figure. We compared the three digital human models of Soldiers wearing IBA with two SAPI plates and a full hydration system to the same three digital human models of Soldiers wearing IBA with two SAPI plates, a full hydration system, and the CREW 3.1 System. The differences in the location of the composite COM resulting from adding the CREW 3.1 System was most extreme for the 5th percentile male figure and was 1.58 inches posterior and 3.91 inches higher than wearing just the body armor and hydration system.

In general, the effect of carrying the CREW 3.1 System is to raise the composite COM and to shift it further back from the carrier. The work by Obusek et al., (1997) suggests that raising the COM is advantageous, while shifting it posteriorly is detrimental. Based on the relatively small amount of COM shift that occurs, it is likely that the effect of this shift on metabolic cost is very small. However, if possible, shifting some of the weight of the CREW 3.1 System to the front of the body would result in less of an effect of the CREW 3.1 System on the anterior/posterior location of the COM and presumably even less of an effect on metabolic cost.

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2. Introduction

The CREW 3.1 System is an IED jamming device that is worn on the back of a Warfighter, weighs about 20 lbs and has an integrated backpack harness. The location of the COM of a backpack relative to the carrier's COM affects the metabolic cost of walking with the backpack (Obusek et al., 1997), with COM locations that are lower to the ground and further posterior from the carrier resulting in greater metabolic cost compared to a higher, closer to the body COM. The purpose of this evaluation was to determine the effect of the mass and COM location of the CREW 3.1 System on the composite COM of a Soldier wearing body armor, a hydration system, and the CREW 3.1 System.

2.1 CREW 3.1 System Description

The CREW 3.1 System consists of a harness, main unit, antenna, two batteries (and pouch) and remote control unit (figure 1). The main unit is attached to the back of the harness. The batteries are contained in a pouch that is attached to the bottom of the main unit. The antenna is connected to the main unit via a flexible goose neck and movable joint. The remote control unit is attached to a strap on the front of the harness and then connected by a cable that is connected to the main unit. The CREW 3.1 System is designed to be worn over the IBA with SAPI plates.

3. Methods

3.1 Human Figure Modeling

Computer-based graphical human figure models have been used to perform ergonomic analyses of workplace designs since the late 1960s (Das and Sengupta, 1995) and have gained widespread acceptance over the past several decades as designers have migrated from traditional paper drafting methods to the use of computers and Computer-aided Design (CAD) software. Human figure modeling programs have proven to be effective tools for evaluating the man-in-the-loop interaction between the operator and the crewstation.

For this modeling effort, the Jack human figure modeling software (Seimens, 2010) was used to help examine the load placement and COM for a dismounted Soldier wearing the CREW 3.1 System.

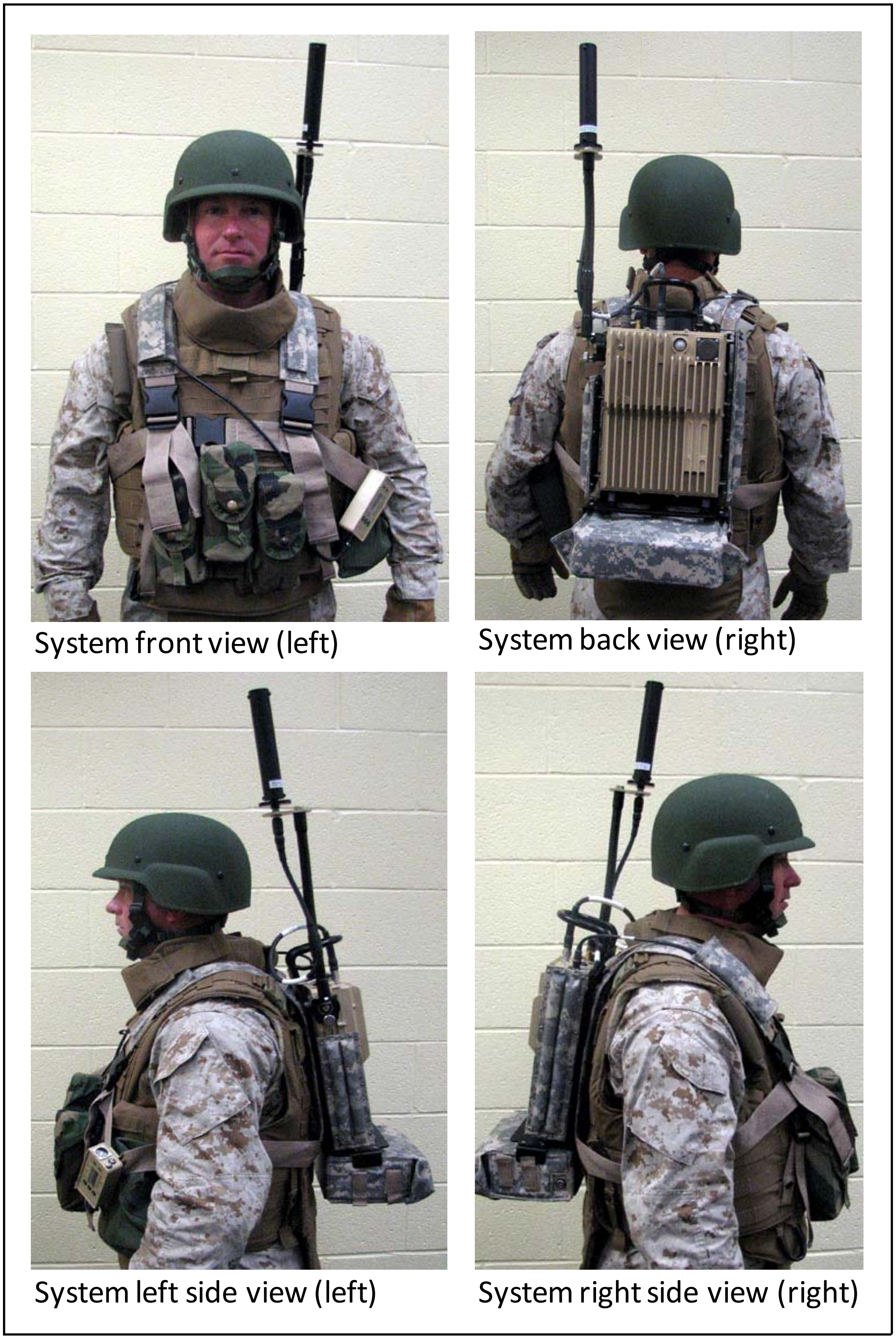

Figure 1. CREW 3.1 System.

3.2 Jack Software

The Jack software is an interactive tool for modeling, manipulating, and analyzing human and other 3D articulated geometric figures (Seimens, 2010). The software also contains a utility for importing anthropometric data that is used to build and size the human figure models. This aspect of the software allows the human factors analyst to tailor the models to represent a specific user population for whom the equipment design is targeted.

The Jack software includes an advanced body scaling utility. Figure 2 is the interface for this utility, which features input for 26 specific body dimensions that can be used to build custom-sized figures. In addition to the advanced scaling utility, a body part scaling interface is also provided. This interface allows the user to scale individual body segments of the human figure.

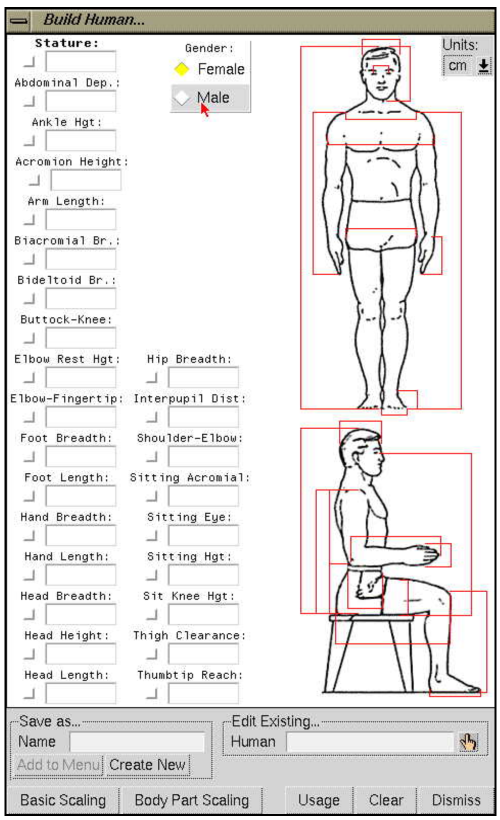

Figure 2. Jack v6.0.2 advanced figure scaling interface.

Three human figure models, a large, mid-sized and small male, were used to examine the load carrying effect of the CREW 3.1 System. The stature for each of the corresponding figures were set at 95th, 50th and 5th percentile male values according to the 1988 ANSUR database (Gordon et al., 1989), and the remaining values for these models were scaled appropriately. These human figure models are shown in figure 3. Body weights were determined to be 216.21, 171.27, and

135.78 lb for the large, mid-sized and small figures, respectively. These are the body weights for the 95th, 50th and 5th percentile male Soldier. Table 1 shows select anthropometric data for these models.

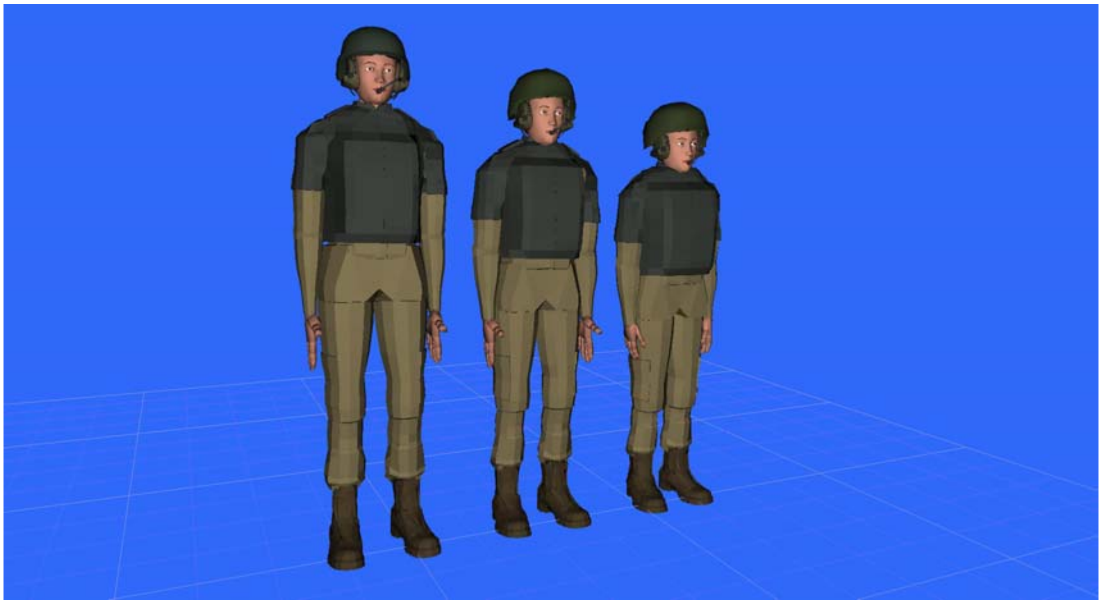

Figure 3. 95th, 50th, and 5th percentile figures used for the modeling effort.

Table 1. Human figure body dimensions in meters (and inches).

Body Dimension	Large Male Figure	Mid Sized Male Figure	Small Male Figure
Sitting height	0.941 (37.1)	0.893 (35.2)	0.858 (33.8)
Acromial sitting height	0.618 (24.3)	0.581 (22.9)	0.552 (21.7)
Sitting eye height	0.819 (32.2)	0.765 (30.1)	0.732 (28.8)
Buttock knee length	0.662 (26.1)	0.613 (24.1)	0.569 (22.4)
Knee height sitting	0.594 (23.4)	0.555 (21.9)	0.520 (20.5)
Foot length	0.291 (11.5)	0.269 (10.6)	0.249 (9.8)
Thumbtip reach	0.885 (34.8)	0.805 (31.7)	0.739 (29.1)
Head length	0.205 (8.1)	0.197 (7.8)	0.186 (7.3)
Head breadth	0.156 (6.14)	0.152 (6.0)	0.143 (5.6)
Hand length	0.211 (8.3)	0.199 (7.8)	0.179 (7.1)
Sitting hip breadth	0.402 (15.8)	0.366 (14.4)	0.310 (12.2)
Chest depth	0.275 (10.9)	0.243 (9.6)	0.208 (8.2)
Bideltoid breadth	0.518 (20.4)	0.491 (19.3)	0.450 (17.7)
Thigh clearance	0.190 (7.5)	0.183 (7.2)	0.151 (5.9)
Foot breadth	0.107 (4.2)	0.101 (4.0)	0.94 (3.7)
Stature	1.869 (73.6)	1.755 (69.1)	1.647 (64.8)
Weight (in pounds)	216.21	171.27	135.78
Weight (percentile)	95th	50th	5th

3.3 COM Model

The composite COM of the CREW 3.1 System and the Soldier (including IBA, SAPI and a full hydration system) was calculated using the methods outlined in Winter (1990), described in general with equation 1:

$$COM_x = \frac{\sum_{i=1}^{n} m_i x_i}{M} \tag{1}$$

where

COM_x = the location of the composite COM along the *x* axis

n = number of segments in the model

m_i = mass of segment *i*

x_i = location of the COM along the x axis of segment *i*

M = total mass of the system

This general equation can also be used to determine the location of the COM along the *y* and *z* axes.

The COM of the Jack figure was based on the location of 12 body segments that included two feet, two lower legs, two thighs, two upper arms, two lower arms and hands, a trunk and a head and neck segment. These segments were defined based on joint locations of specific joints as outlined in Winter (1990). The mass of each body segment was determined based on the body mass of the Jack figure and the anthropometric tables in Winter (1990). The location of the COM of each body segment was determined based on anthropometric tables in Winter (1990) and the location of specific body joints (determined from the Jack figure).

In addition, the composite COM of the Jack figure plus the CREW 3.1 model included IBA, two SAPI plates, and a hydration system that is worn on the Soldier's back. The COM of the IBA was assumed to be in the center of the IBA when the IBA was correctly fitted to the Jack figure. This is based on the assumption that the amount of material on the front of the IBA is equivalent to the amount of material on the back and also means the COM of the IBA was centered along the midline of the body (mediolaterally). The SAPI plates were included in the analysis and were placed in the IBA worn by the digital human model. The COM of each SAPI plate was assumed to be the center of the plate.

The mass and COM location of the CREW 3.1 was provided by the contractor developing the system.

4. Results

The green arrow in figure 4 indicates the location of the COM of the CREW 3.1 System. This information was provided by the contractor developing the system and was input into the Jack model for illustration purposes.

Figure 4. CREW 3.1 System. The green marker shows the COM of the backpack, part of the backpack was made invisible to illustrate the location of the COM.

In figures 5–7 the yellow triangles center on the COM of the Soldier with no body armor or backpack. In figures 6 and 7 the orange triangles center on the composite COM of the Soldier, body armor and the CREW 3.1 System. Most importantly, note in figure 7, the relatively small shift in COM caused by adding the CREW 3.1 System.

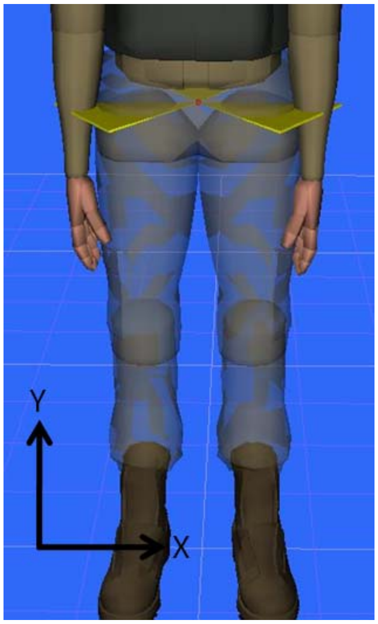

Figure 5. COM of Soldier. Mass of backpack, armor or any other equipment is not included in the calculation of this COM.

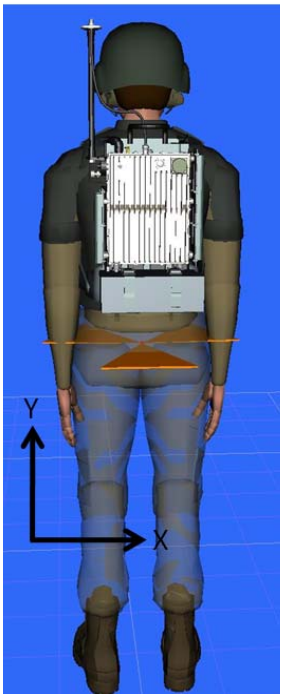

Figure 6. Composite COM of Soldier, CREW 3.1 System, hydration system and body armor with SAPI plates.

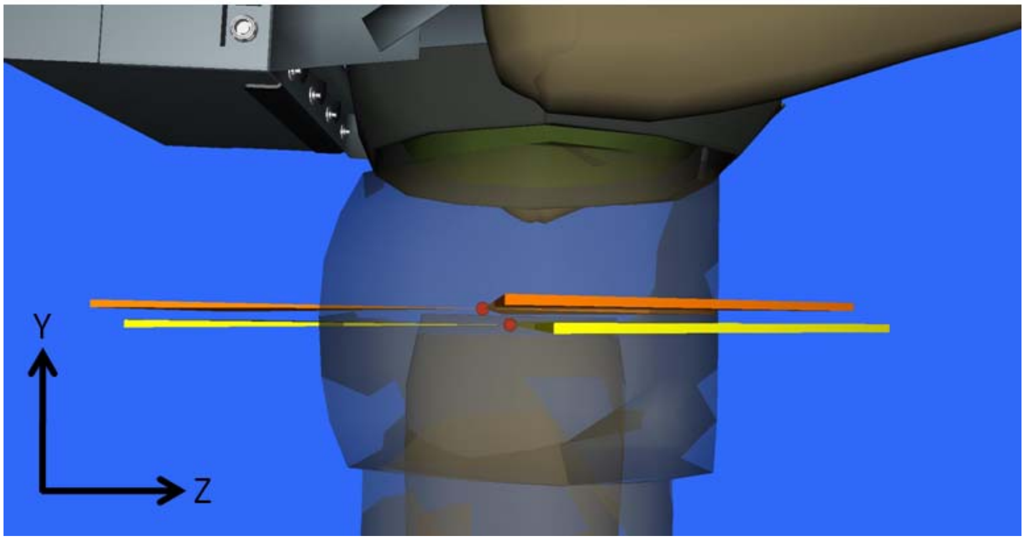

Figure 7. Relative location of composite COM (orange) and Soldier COM (yellow). Note the posterior and relatively higher composite COM compared to the Soldier COM.

We compared the three digital human models of Soldiers wearing IBA with two SAPI plates and a full hydration system to the same three digital human models of Soldiers wearing IBA with two SAPI plates, a full hydration system, and the CREW 3.1 System. We assumed that adding the CREW 3.1 System would not affect the location of the SAPI plates or the hydration system. The differences in the location of the COM are summarized in table 2. For reference, the figure 8 coordinate system used for table 2 shows the coordinate system used for the analysis.

Table 2. Effect of CREW 3.1 System on composite COM.

Percentiles	**Coordinates**		
	X	**Y**	**Z**
95th	–0.02	3.36	–1.22
50th	0.03	3.61	–1.41
5th	0.03	3.91	–1.58
—	Medial-Lateral Negative values indicate further toward the right	Vertical Positive values indicate a higher COM	Ant/post Negative values indicate further 'back'

Note: Units are in inches.

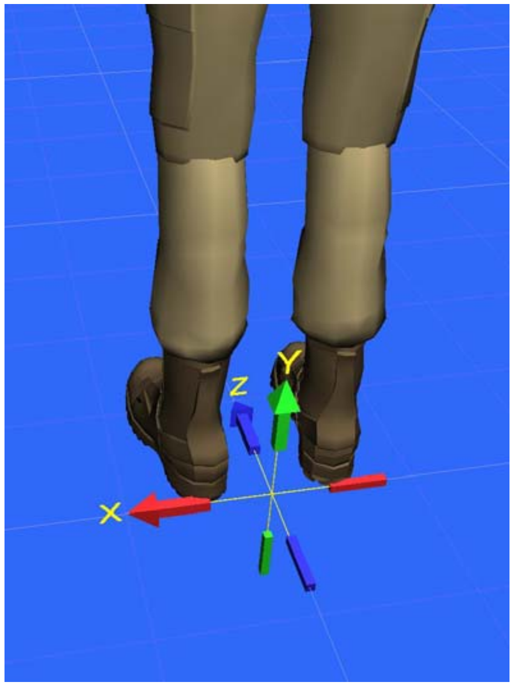

Figure 8. Coordinate system used for table 2.

5. Discussion

Previous research on the effects of backpack COM on metabolic cost indicate that a COM closer to the carrier's body and higher on the torso results in lower metabolic cost than a COM that is further away from the carrier and lower on the torso (Obusek et al., 1997). Based on the analysis of COM location, it is clear that the CREW 3.1 System has the largest effect on the COM of the 5th percentile male. This is likely due to the fact that mass of the backpack represents a larger percentage of the 5th percentile male's body weight than the 95th percentile male.

In general, the effect of carrying the CREW 3.1 System is to raise the composite COM and to shift it further from the carrier. The work by Obusek et al., (1997) suggests that raising the COM is advantageous, while shifting it posteriorly is detrimental. Based on the relatively small amount of COM shift that occurs posteriorly, it is likely that the effect of this shift on metabolic cost is very small. However, if possible, shifting some of the weight of the CREW 3.1 System to the front of the body would result in less of an effect of the CREW 3.1 System on the Z component of the COM and presumably even less of an effect of metabolic cost.

While previous research demonstrates an effect of COM location on metabolic cost, missing is a model that allows for a prediction of metabolic cost based on COM locations. Such a model would be useful for the current analysis because it would allow for researchers to provide systems developers with a greater understanding of the magnitude of change in metabolic cost that can be attributable to the shift in composite COM.

6. References

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List of Symbols, Abbreviations, and Acronyms

ANSUR	U.S. Army Anthropometry Survey
CAD	Computer-aided Design
COM	center of mass
IBA	Interceptor Body Armor
IED	Improvised Explosive Device
SAPI	Small Arms Protective Inserts

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